# SiC/SiC COMPOSITES FOR APPLICATIONS ABOVE 2600°F

**J.A. DiCarlo and R.T. Bhatt**
NASA Glenn Research Center
Cleveland, Ohio

**Research Supported by the**
**NASA Ultra Efficient Engine Technology (UEET) Program**
**NASA Glenn Internal Research & Development Fund**

**Presented at 28th Annual Conference**
**on Composites, Materials, and Structures**
**RESTRICTED SESSIONS**
**Cape Canaveral, Florida, January 26, 2003**

*Key Words*: **SiC/SiC composites, constituents, processes, creep-rupture, thermal conductivity, high temperature**

## Abstract

SiC/SiC Composites for Applications above 2600°F

**J.A. DiCarlo* and R.T. Bhatt**
**NASA Glenn Research Center, Cleveland, OH**

**Using data from panels with 2D-woven architectures, this presentation describes progress in identifying advanced constituent materials and processes for achieving a high conductivity SiC/SiC composite system with long-term structural life under oxidizing conditions at temperatures above 2600°F. A key factor for this progress is the development of approaches at NASA GRC that allow the constituent SiC fiber and SiC matrix to display high thermal conductivity, high creep-rupture resistance, and high microstructural stability at temperatures above 3000°F. Another important factor is the avoidance of free silicon in the SiC matrix, thereby providing the composites with the capability for extended service above the silicon melting point (2550°F). The effects of utilizing various materials and processes for the SiC matrix are presented and discussed.**

## Introduction

A major thrust under a variety of NASA aerospace component development programs such as UEET and NGLT is to develop and demonstrate ***constituent materials and processes*** that allow the fabrication of ***ceramic matrix composites*** with

***Optimized structural and environmental durability properties up to as high a temperature as possible in order to allow***

- ***Longer life at lower temperatures***
- ***More reliable operation in case of EBC/TBC loss***
- ***Reduction of EBC/TBC thickness requirement***
- ***Enabling of new high temperature applications***

## SiC/SiC Advantages for High Temperature CMC Aerospace Applications

***Versus Oxide/Oxide Ceramic Composites:***

- Higher strength, temperature capability, creep-rupture resistance, thermal conductivity
- Lower permeability

***Versus Carbon Fiber Composites (C/SiC, C/C):***

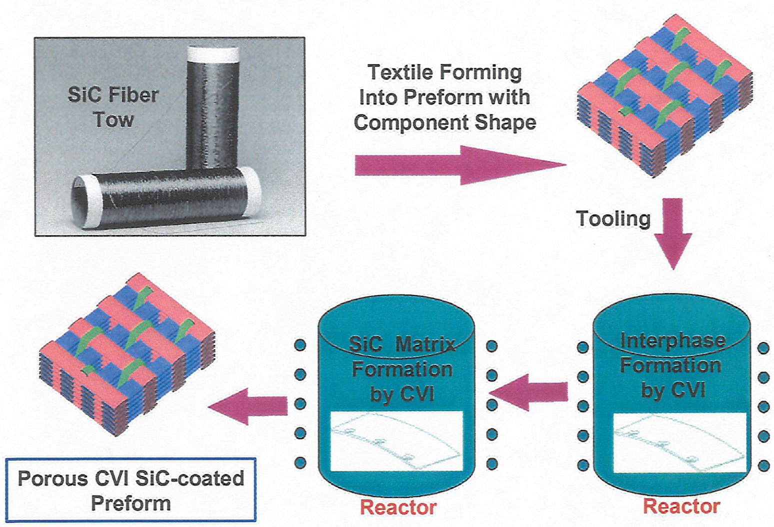
- Higher oxidative durability, thermal conductivity, more predictable life
- Lower permeability due to F/M CTE match

***But until recently, SiC/SiC limited to ~2200°F due to intrinsic SiC fiber and SiC matrix thermal stability and creep-rupture issues***

## Objective / Outline

- Present brief review of NASA efforts to demonstrate advanced fiber and matrix materials and processes that allow SiC/SiC systems with long life *to 2400°F*
- Present results of current efforts to push SiC/SiC materials and processes *beyond 2600°F*

## NASA Basic Process Route for SiC/SiC




### *Process Advantages*

- *CVI SiC is dense , highly conductive, creep resistant constituent*
- *CVI SiC volume fraction can be varied from ~1 to >50 %*
- *Pores can then be filled by multiple processes (CVI, MI, PIP, etc.)*
- *Process route is robust and can be practiced by multiple vendors*

## SiC/SiC Systems Developed under NASA EPM and UEET Programs

**System Code:** N = NASA, xx = Upper Use Temperature (°F) / 100
**Upper Use Temperature:** Rupture time >500 hours in air under a design tensile stress ~60% of elastic limit

| | N22 (EPM MI) | N24A (UEET 01/01) | N24C (UEET 01/03) |
|---|---|---|---|
| Upper Use Temperature | 2200°F | 2400°F | 2400°F |
| Fiber | Sylramic | Sylramic-iBN | Sylramic-iBN |
| Interphase | BN-based | BN-based | BN-based |
| CVI SiC Matrix Content | ~20 vol. % | ~20 vol. % | ~35 vol. % (annealed) |
| Pore Filler | SiC slurry + MI Si | SiC slurry + MI Si | MI Si |

## NASA Approach for SiC/SiC Demonstration

### 2D Panel Fabrication:

- 5HS 0/90 SiC fabric with balanced ends per inch
- ~35 to 40 total fiber vol. % at panel thickness of ~80 mil

### Key Tests for Fiber-Matrix Capability

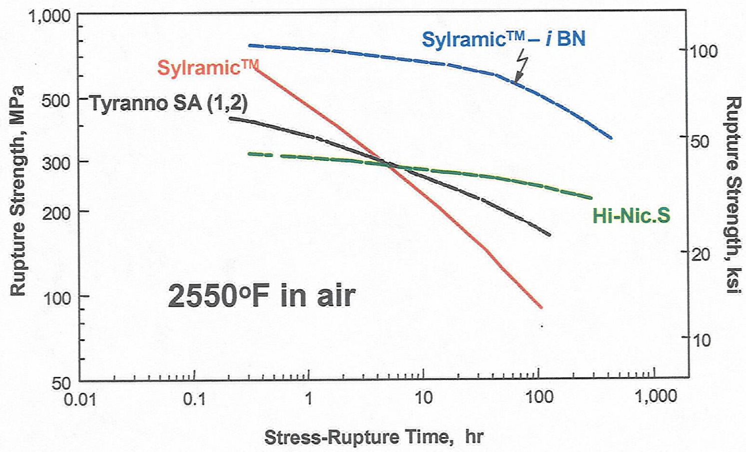
- Tensile coupons cut from panels *with no edge seal coatings* and tested in air in 0° direction for
  - Stress-Strain at room temperature
  - Creep and rupture behavior *at goal temperatures*
- Thru-thickness Thermal conductivity

### Key Goals

- Rupture time >500 hours at stresses ~60% of elastic limit
- Thermal conductivity near that of best SiC/SiC (CVI + MI)

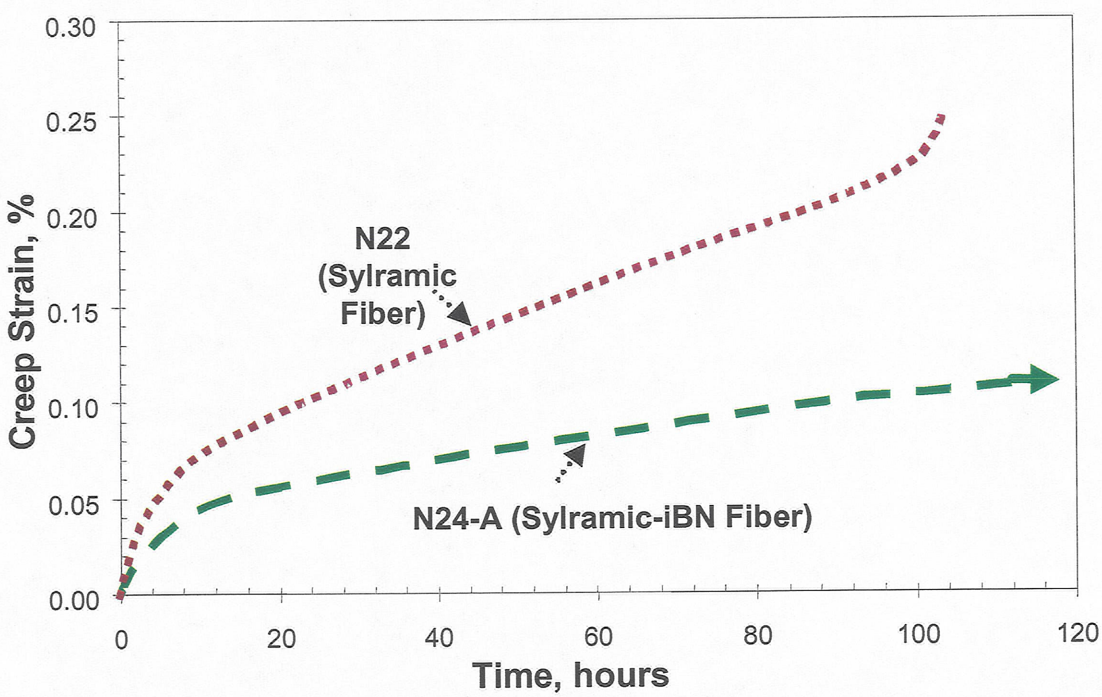
## NASA-Developed Treatment for Sylramic Fibers

- *Forms thin protective in-situ BN coating on fiber surface*
- *Retains high strength and thermal conductivity of Sylramic*
- *Yields Sylramic-iBN Fiber with best high-temperature creep and rupture resistance for any SiC fiber*

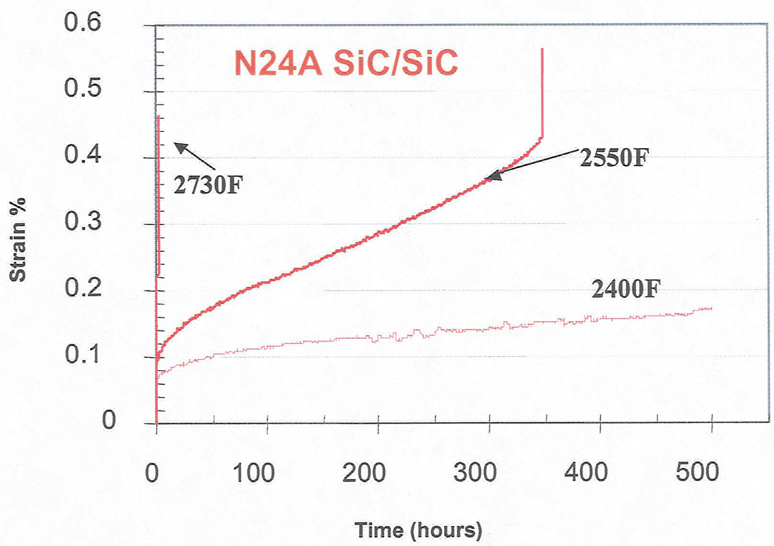



***NASA-AF collaborative-funding activities currently exist with ATK COI Ceramics for transfer of Sylramic-iBN technology and commercialization of Sylramic and Sylramic-iBN fibers in early 2004.***

## Creep-Rupture of N22 and N24A (CVI+MI) SiC/SiC at 2400°F in air at 15 Ksi

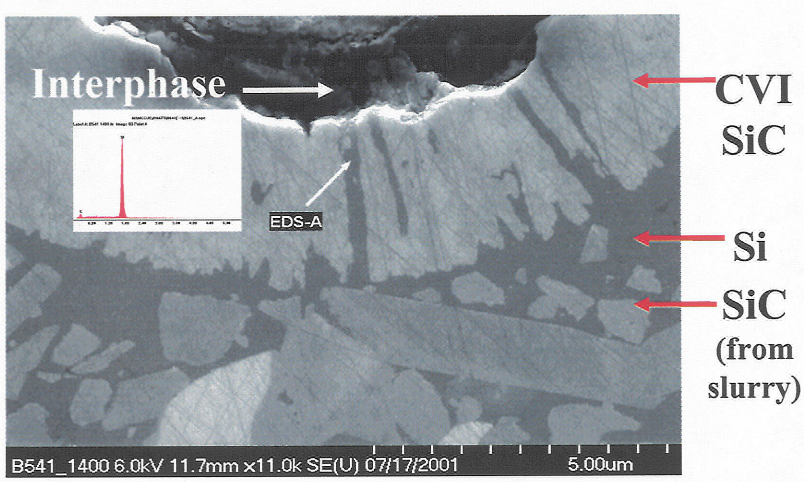


## Creep-Rupture of N24A (CVI+MI) SiC/SiC in air at 15 Ksi



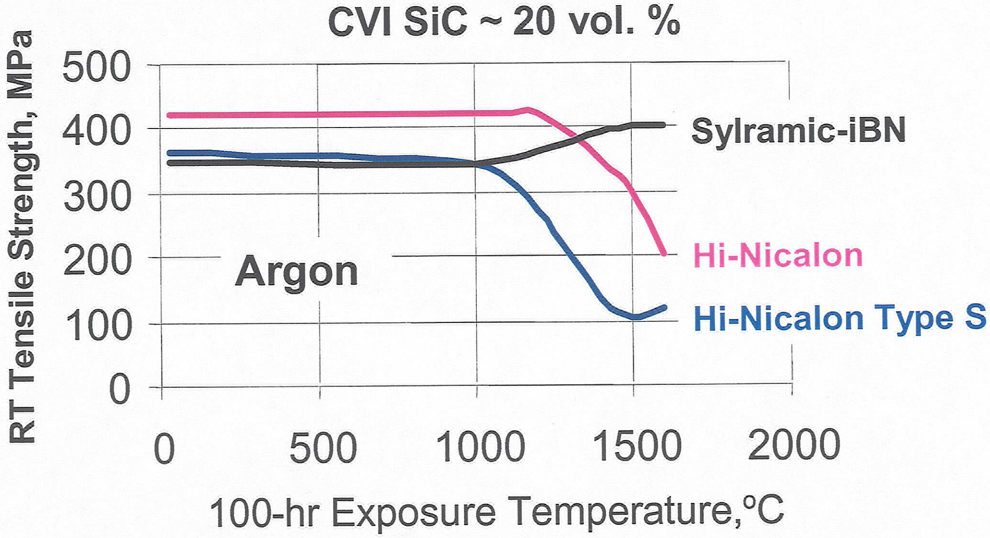

*Lifetimes of C/SiC under ~ same conditions are ~ 1 hr*

## Fiber-matrix Region for N24A (CVI + MI) SiC/SiC Exposed In Argon at 2550$^0$F for 100 Hours




*For CVI + MI matrices near the Si melting point, SiC fibers begin to lose strength and CVI matrices creep more due to Si diffusion through CVI SiC and BN interphase*

## Thermal Stability of Porous CVI SiC Preforms

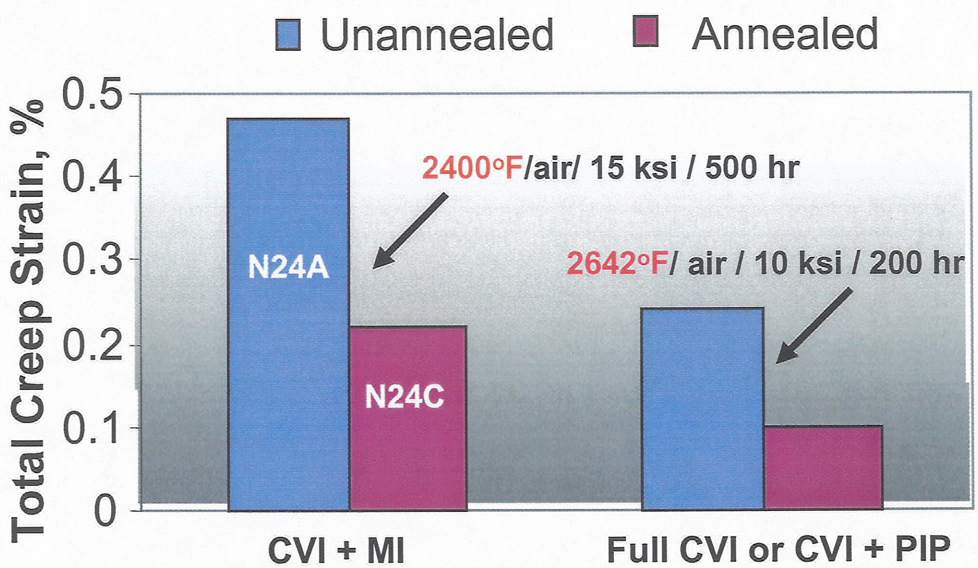



*Intrinsic thermal stability of Sylramic-iBN SiC fiber allows*
- *Highest temperature capability for CVI SiC matrix composites*
- *Possibility for annealing total composite system to enhance SiC matrix performance without loss in composite strength*

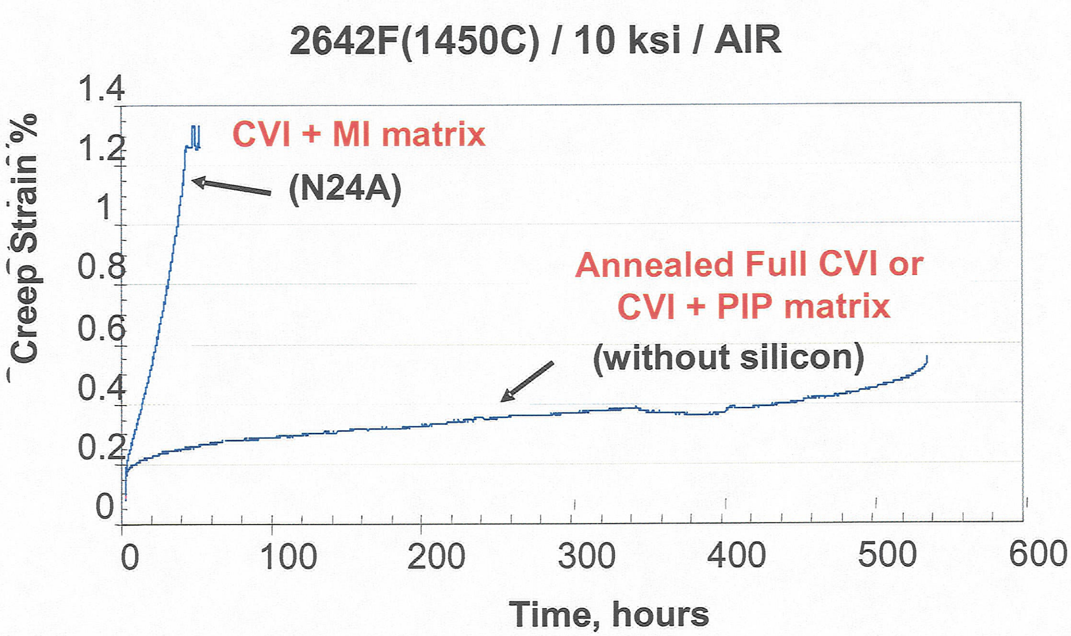
## NASA Current Approaches for *2600°F and beyond* SiC/SiC Systems

- Continue to use *Sylramic-iBN SiC fiber* and *CVI BN-based interphase*
- Continue to use dense *CVI SiC matrices* to provide environmental protection, creep-rupture resistance, thermal conductivity, and multi-directional performance.
- But use *Si-free matrix processes* to fill CVI SiC porosity.
- Matrix materials/processes for this presentation:
  - *Full CVI SiC* from GEPSC with ~50 vol % CVI SiC
  - *CVI + PIP SiC* from Starfire with ~35 vol % CVI SiC
  - *High Temperature Annealing* of final panels to remove matrix defects and improve CMC creep-rupture resistance and thermal conductivity

## Annealing Effects on Creep for Various Sylramic-iBN SiC/SiC Systems

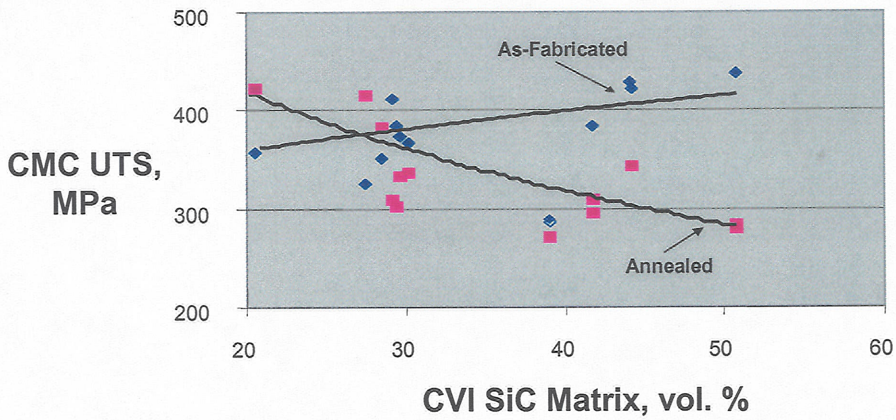



## Creep-Rupture Comparison at 2642°F for Various Sylramic-iBN SiC/SiC Systems

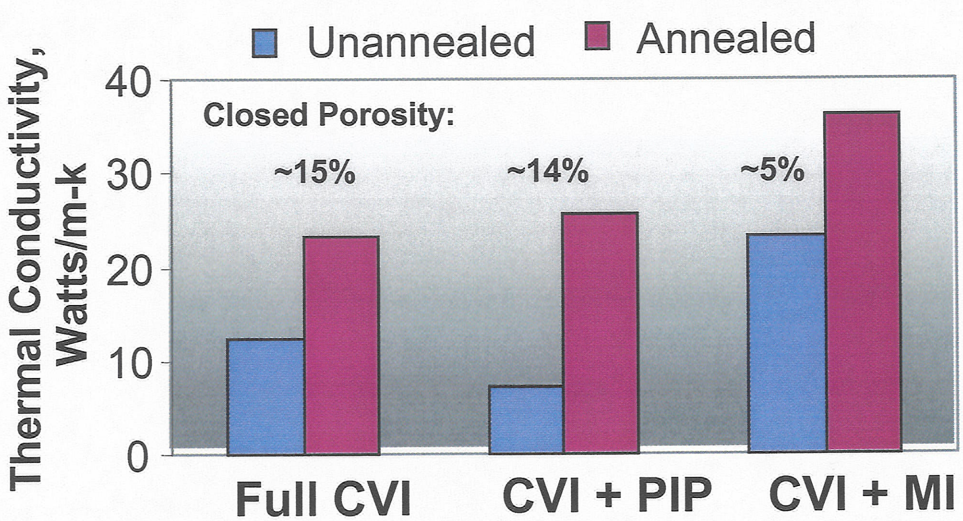


## Issues with High Content CVI SiC Matrices

- CVI SiC cannot adequately fill intertow spaces, resulting in
  - *High content of closed porosity*
  - *Low thermal conductivity*
  - *Low matrix cracking strength*
- Also, due to low temperature deposition, CVI SiC typically contains *free silicon which can attack SiC fibers* during high temperature annealing of the matrix and CMC




## Thru-Thickness Thermal Conductivity at 20°C of Sylramic-iBN CMC with Various Matrix Types




*Annealed SiC/SiC with medium CVI plus PIP matrix currently shows best combination of high UTS, long structural life above 2600°F, and good thermal conductivity*

## Summary and Conclusions

- NASA has demonstrated state-of-the-art high-temperature SiC/SiC composites by developing ***advanced materials and process technologies***
- Key technologies are the development of the ***Sylramic-iBN SiC fiber*** and ***high temperature annealing of the total SiC/SiC system*** to significantly improve matrix properties (thermal conductivity, creep-rupture resistance)
- For long-term operation above 2600°F, the ***Sylramic-iBN fiber with a porous medium-content CVI matrix that is filled with a Si-free PIP-derived filler*** currently appears to be a promising system direction, but porosity issues still need to be addressed.
- NASA technologies discussed here are ***available for transfer***, and resulting fiber and CMC property data-bases are being ***incorporated in MIL 17 CMC Handbook***.

## Future Directions

- On-going NASA research efforts for high-temperature SiC/SiC aerospace components are currently seeking ***more creep and rupture resistant SiC fibers***, ***lower porosity and higher conductivity SiC matrices and BN-based interphases***, and ***improved processes for forming the complex fiber architectures*** required for many components.
- Because dense ***CVI SiC matrices*** provide environmental protection, high creep-rupture resistance, high thermal conductivity, and multidirectional structural performance, they are being used as the ***prime matrix constituent*** with a variable content that is being filled with ***Si-free high-temperature fillers.***